

THE NDBC IOOS[®] DATA ASSEMBLY CENTER

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Abstract - The National Data Buoy Center, located along the Mississippi Gulf Coast, began operations in 1967 as a program under the U.S. Coast Guard. In 1970, NOAA was formed and NDBC was transferred to that agency. The first buoys operated and managed by NDBC were large, 12-meter discus buoys that were constructed of steel and deployed in deep waters off the U.S. East Coast and in the Gulf of Mexico. By 1979, NDBC maintained 26 stations: 16 in the Pacific Ocean, 7 in the Atlantic Ocean and 3 in the Gulf of Mexico. NDBC deployed 8 more stations in the Great Lakes during the 1980s. Today, NDBC operates 115 moored weather/ocean platforms, 52 coastal marine stations, 39 deep-ocean tsunameters and 55 tropical atmosphere ocean moored platforms in the equatorial Pacific.

In response to the growing number of stations, NDBC established a data quality assurance group that quality controls data from all NDBC platforms, on a daily basis. The real-time observations are released through the NWS Telecommunications Gateway in Silver Spring, Maryland and sent to the World Meteorological Organization (WMO) Information System telecommunication services. Automated quality control is applied before the observations are released (checking for parity errors, range checks for spurious points, time continuity checks and zero wave heights). In addition, the observations are evaluated after 45 days, edited and sent to U.S. archive data centers for permanent storage.

In 2001, NDBC began receiving, processing, quality controlling and disseminating observations from 10 stations deployed by the Gulf of Maine Ocean Observing System. Weather Forecast Offices, mariners, transportation officials and the public wanted to ensure that the observations received NDBC's "stamp of approval" before they were used in daily operations. In July 2006, with funding from the NOAA Integrated Ocean Observing System (IOOS[®]) Program, NDBC started the IOOS[®] Data Assembly Center – operating 24 hours a day, seven days a week in response to increasing marine platforms, real-time observations and the need to support buoy recovery and deployment operations in the far reaches of the Pacific and Indian Oceans.

1. INTRODUCTION

Marine observations in the U.S. are slowly but steadily becoming integrated and standardized by the many number of marine platforms deployed around the U.S. – through the tireless efforts of the U.S. IOOS[®] Program. The U.S. Integrated Ocean Observing System (IOOS) Data Integrated Framework (DIF) is an initial effort to establish the technical infrastructure, standards and protocols needed to

improve delivery of core ocean variables to numerical models, registries and data base servers. Within the next few years, data requestors will be able to request real-time, quality controlled marine observations for waters around the U.S., and receive whatever observations are available at the time, regardless of the data provider. The next step is to work with the WMO/IOC, and nations that are establishing their own IOOS[®], and integrate the U.S. efforts with the international community. The NDBC IOOS[®] DAC is already working with a few nations to supplement their data assembly needs as they focus on deploying marine platforms – thus moving the DAC into the international arena.

The NDBC web: <http://www.ndbc.noaa.gov/ioos.shtml> provides a description of the IOOS[®] program at NDBC. Partners collect physical meteorological and oceanographic observations, in real-time and send the observations to a server at NDBC. Once those observations are received, they are treated as if they were NDBC observations – and put through the same automated and manual quality control processes as NDBC's processes. NDBC and the IOOS community have developed the capability to make a variety of measurements, including:

- Atmospheric pressure
- Wind direction, speed, and gust
- Air and water temperature
- Wave energy spectra (non-directional and directional)
- Water-column height (Tsunami Detection)
- Relative humidity
- Ocean current velocity
- Precipitation
- Salinity
- Solar radiation
- Visibility
- Water level and water quality.

The NDBC marine platforms, IOOS[®] partner platforms, National Ocean Service (NOS) National Water Level Observation Network, and Gulf of Mexico Oil and Gas network are comprised of sites offshore and along most of the U.S. coastline, including Alaska, Hawaii, and the Great Lakes. The importance of accurate data from these stations

cannot be over emphasized. The maritime community has come to rely on the data for the safe conduct of operations, and the marine network often provides the only real-time measurements available from remote, data sparse areas.

The primary user of real-time NDBC data is the NWS which uses the data for the issuance of warnings, analyses, forecasts and for initializing numerical models. The general public has access to the data in real-time via the NDBC web site. NOAA and external users can access the data in real time via NOAAPORT. See <http://www.weather.gov/noaaoprt/html/noaaoprt.shtml> for more information. Each month, the data that have been collected during the previous month from NDBC operated moored buoys and C-MAN stations undergo further quality control by NDBC and are processed for archival at the National Climatic Data Center (NCDC), Asheville, NC, and the National Oceanographic Data Center (NODC), Silver Spring, MD. Historical data are also available at the NDBC web site. Only data that have passed all automated QC checks and manual review, and have met NDBC standards for accuracy, are archived.

Tropical Atmosphere Ocean (TAO) data and tsunameter data are archived post-deployment rather than monthly. TAO data undergo a delayed mode QC process prior to archival at NODC. Tsunameter data are not quality controlled prior to archival. Data are packaged and sent to the National Geophysical Data Center (NGDC) for archival.

Partner data are not archived at NCDC or NODC by NDBC at this time. Current it is the responsibility of the partners to archive their data. Historical data from these partner stations can be found on NDBC's website. However, NDBC is working closely with the archive centers to develop quality control flags that will indicate which data received additional QC and which did not.

II. THE QUALITY CONTROL PROGRAM

The primary objective of the NDBC QC program is to ensure that NDBC and partner sensor systems provide measurements that are within NDBC total system accuracy. NDBC total system accuracy may be defined as the difference between the NDBC measurement and the true ambient value. It is a function of sensor accuracy, errors induced by the buoy or platform, and to some extent, the accuracy to which we can monitor the measurement in its remote environment. See the NDBC Web page, <http://www.ndbc.noaa.gov/rqa.shtml> for the system accuracies for the various NDBC payloads.

However, NDBC believes that the accuracy achieved is often considerably better than these stated accuracies based on special field comparisons. These comparisons between duplicate sensors on the same buoy or inferred through post calibrations are given in Table 1. Also listed in Table 1 are

the standards required by the [1]. When duplicate sensors were available, the accuracies were computed in an established manner by computing a root mean square combination of bias (or mean difference over the course of a month) and the standard of deviation of differences.

These accuracies are often considerably better than the total system accuracies. For example, the total system accuracy for wind speed is plus or minus 1 m/s. There are two reasons why NDBC states the system accuracies conservatively. First, this states the degree to which we can quality control the measurement in the field. Monitoring tools, such as comparison with numerical models, graphical displays, and the results of any analyses, do not allow us to determine a 0.5 m/s error in wind speed. Second, there are some rare environmental conditions, such as high waves, which may temporarily preclude us from achieving the desired accuracies.

Table 1. Accuracies Achieved During Field Comparisons.

Measurement	WMO Requirement	NDBC Accuracy	Basis
Air Temperature	0.1 deg. C	0.09 deg. C	Duplicate sensor comparison
Water Temperature*	0.1 deg. C	0.08 deg. C	Duplicate sensor comparison
Dew Point	0.5 degrees C	0.31 deg. C	Post calibration
Wind Direction	10 deg	9.26 degrees	Adjacent buoy comparison
Wind Speed	0.5 m/s or 10%	0.55 m/s	Duplicate sensor comparison
Sea Level Pressure	0.1 hPa	0.07 hPa	Duplicate sensor comparison
Wave Height	0.2 m or 5%	0.2 m	Comparison to standard
Wave Period	1 s	1 s**	Comparison to standard
Wave Direction	10 deg	10 deg	Comparison to standard

An NDBC Technical Services Contractor (NTSC) staffed by engineers, meteorologists, computer scientists,

and other specialists, provides support in response to technical directives initiated by NDBC. Data quality analysts in the NDBC Data Assembly Center review the day-to-day quality of data and delete questionable data from those data sets destined for archival, and prohibit questionable data from further public release. Physical and computer scientists in the NDBC Data Systems Department develop, test, and implement automated QC procedures.

The NDBC QC program may be viewed in two parts. First, there are real-time automated QC checks done exclusively by computers at the NWS Telecommunications Gateway (NWSTG) in Silver Spring, MD. The first category of these are gross error checks that detect communication transmission errors and total sensor failure. Data flagged by these checks are virtually certain to be erroneous. These checks, however, can be overridden when storms or other unusual environmental phenomena are anticipated that would generate out of the ordinary, but valid measurements. The second category of automated checks identifies data that may not be grossly in error, but for some reason, suspect. Data so identified will be released, but will undergo additional scrutiny within 24 hours by NTSC data quality analysts. They perform manual inspection using computer-generated analytical aids, graphical displays, and the results of any automated QC checks to identify the often subtle degradation of systems and sensors. Analysts integrate and compare NDBC data with relevant NWS and National Environmental Satellite, Data, and Information Service (NESDIS) products, such as weather observations, numerical weather analyses and forecasts, weather radar, and satellite images.

III. OBSERVATION DATA FLOW

A discussion of the flow and processing of NDBC data will be useful in understanding the NDBC QC process. This section describes the most important data paths that are used by NDBC and its users to acquire NDBC data. The major steps involved in applying automated QC during the data production process are also briefly described.

The data paths involving the transmission of data from C-MAN and moored buoy platforms are shown in Figure 1 for GOES and Figure 2 for Iridium Satellite LLC, referred to as Iridium describing both the service and system.

For NDBC operated platforms, the acquisition and telemetry of sensor data on each platform are controlled by an onboard microprocessor referred to as “the payload”. Data are transmitted in different ways. Data are primarily transmitted from the platform via a Geostationary Operational Environmental Satellite (GOES) (Fig 1) to the NESDIS Data Acquisition and Processing System (DAPS) at Wallops Island, VA; (NDBC has a local Direct Readout Ground Station (DRGS) to collect sensor data when the Wallops Island line or system is down). Then, data at

DAPS/DRGS are routed to redundant NDBC computer systems at NWSTG where these systems decode the data, perform automated QC checks, and generate reports in standard World Meteorological Organization (WMO) format.¹ After the NDBC computers process the data, they are sent to a message routing system at NWSTG where data are released. These real-time reports are released in collective bulletins to users via the NWS Family of Services (FOS) network, the Global Telecommunication System (GTS), and NOAAPORT. WMO bulletins received at NDBC via NOAAnet are used to update real-time observations on the NDBC Web site. Separate, private bulletins that are sent only to NDBC are also generated at the NWSTG to transmit the processed data and quality control flags. These bulletins contain the complete set of data acquired at all NDBC operated stations, and are used to update the NDBC Oracle[®] database at Stennis Space Center, Mississippi (SSC), in near real-time. Data quality analysts at NDBC access the database to note the occurrence of flagged data and conduct further quality control.

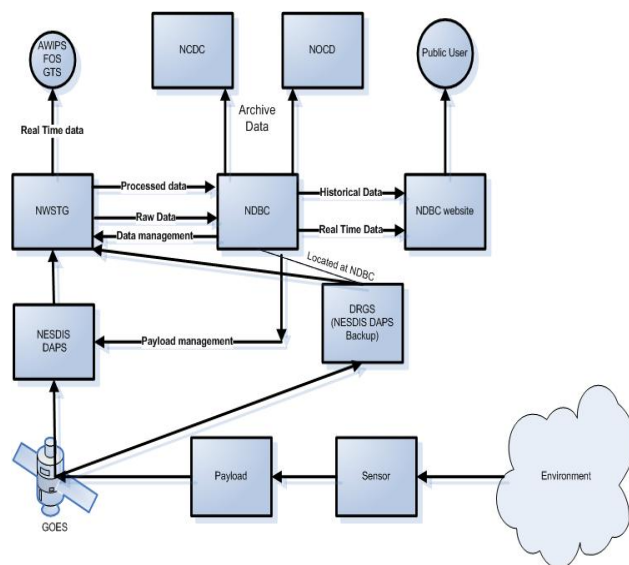


Fig. 1. C-MAN and Moored Buoy Data Paths Using GOES Satellites.

Some stations transmit data via Iridium satellites to the Iridium gateways in either Hawaii or Arizona. (Fig 2) The data are then routed to an NDBC server designated for Iridium data at the NWSTG. The data are then routed to the same redundant computer systems that GOES data are routed to at NWSTG. At this point, the data from Iridium stations go through the process described above for stations transmitting data via GOES. Stations with Iridium communications have two-way communications capability, and the communications from NDBC to the buoys is referred to as back channel capability. NDBC can send

¹ C-MAN stations report using a U.S. National code form, C-MAN code that closely resembles WMO FM12 SYNOP code.

commands directly to the buoy. The NDBC personnel use an application that connects to the server designated for Iridium data at the NWSTG and issues a command. That command is routed to the Iridium gateway, then to the Iridium satellite, and down to the payload it was intended for. Back channel commands allow NDBC to troubleshoot or maintain a payload remotely. Data management information and parameters, to properly process the data, are maintained and updated in the NDBC database at SSC. When changes are made in the NDBC database, the information on the redundant NDBC computers at NWSTG is also updated. This information mainly consists of scaling parameters, QC thresholds, or instructions to prevent the release of measurements from failed sensors. Payload management information in Platform Data Tables, such as GOES channels, are maintained and updated at NDBC. NDBC personnel telnet into the servers and/or speak with personnel at DAPS to manage the information.

The DRGS permits processing of raw data at NDBC for test purposes or as a backup to update the database if a system failure occurs at NWSTG or DAPS. Partner stations provide NDBC with data in different ways. For most partners, NDBC will create ftp accounts for partners to send their data. NDBC obtains NOS's data from their ftp server. Other partners allow NDBC to extract data using web services. All partner data are routed to the redundant NDBC computers at the NWSTG where they go through the same QC process as NDBC operated stations.

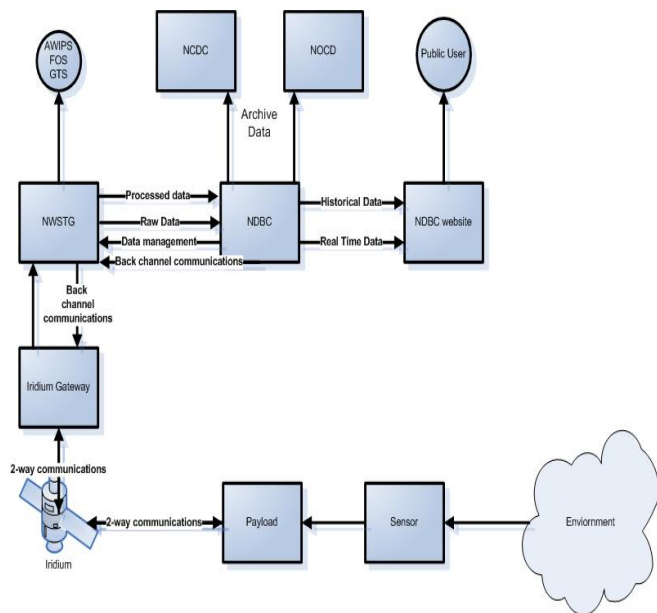


Fig. 2. C-MAN and Moored Buoy Data Paths Using Iridium Satellites.

DART® II buoys transmit data similarly to weather buoys that use Iridium satellites. Sensors on the ocean floor send data to the buoy acoustically. The buoy records and transmits data to a server in Tempe, AZ via Iridium

satellites. The data are then routed to an NDBC server, co-located with NWSTG, where they are processed and disseminated in the same fashion as weather buoy data. The Tsunami Warning Centers and NDBC can send instructions to the sensor via back channel communications as described previously.

IV. REAL-TIME PROCESSING

The vast majority of automated quality control checks are performed during real-time processing on the NDBC computers at the NWSTG. A few checks require data that are not available during processing at NWSTG but are applied by programs run at NDBC after the data are inserted into the database. A program that compares NDBC measurements with numerical model fields is an example.

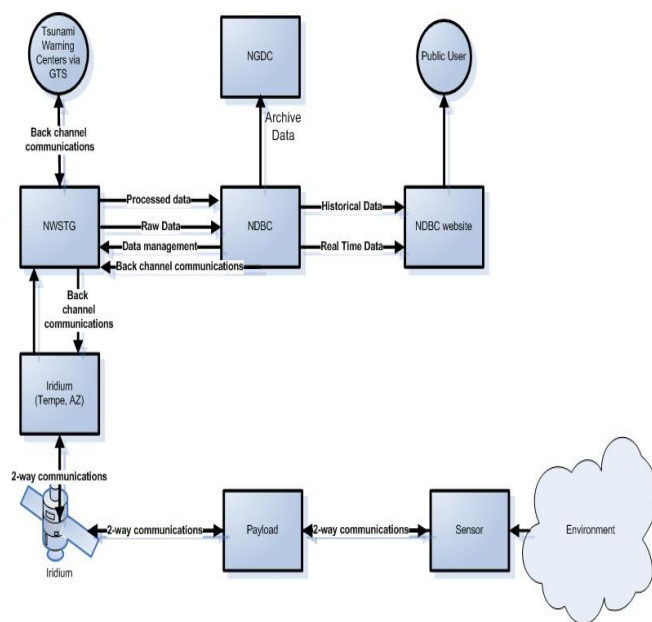


Fig. 3. Tsunameter II Data Flow.

The flow of data during real-time processing at the NWSTG is depicted in Figure 4. When unprocessed data arrive at the NWSTG from partners, DAPS, or Iridium, it is routed to a queue where it awaits the QC process. The first step involves extracting the raw message data and converting them to meaningful geophysical units. This process not only involves decoding the raw data, but also applying scaling factors and performing calculations for derived data. This is also the first point in the process where automated QC routines are applied. The raw data are checked for errors as a result of truncated or garbled messages. Wave and continuous wind measurements are hard flagged and not released if the message strings containing these data have errors. Other measurements, missing as a result of transmission errors, are also identified and individually flagged at this point in the process. The

next steps are the application of the QC algorithms where measurements are checked against QC parameters and hard or soft flagged if necessary. Data are also stored for use in subsequent hour's time continuity algorithms. Measurements identified as erroneous with hard flags are deleted from release, and the appropriate encoded messages are generated and grouped under the appropriate geographic bulletin header for transmission. Private bulletins are generated and transmitted to NDBC which contain all measurements and flags to update the NDBC database. A process monitor permits personnel at NDBC to monitor the flow of information at the NWSTG.

During each step in the process, a parameter manager applies the appropriate parameters which include such items as scaling coefficients, quality control limits, sensor hierarchy designations, and output bulletin organization. The parameters are updated and maintained by data analysts through the National Data Buoy Center Enterprise Management Information System (NEMIS) interface to the NDBC Oracle[®] database. Whenever changes are made, they are transmitted to update the NWSTG parameter files.

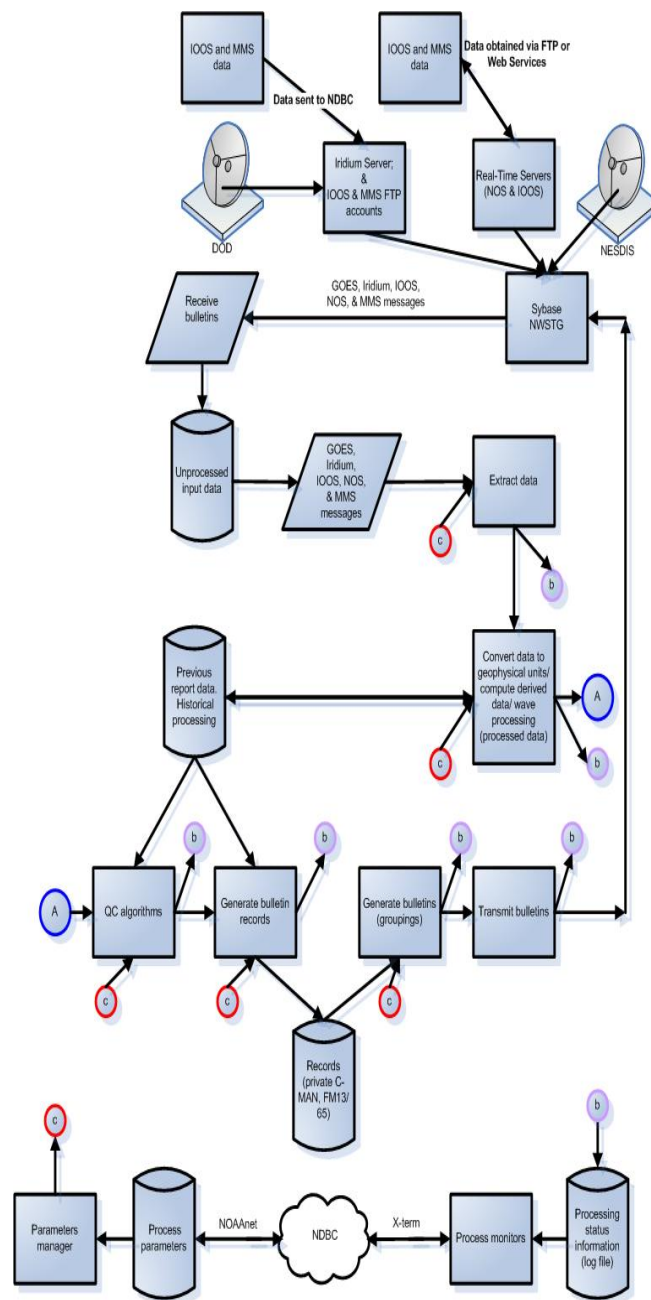


Figure 4. NDBC Real-Time Processing at NWSTG.

Raw messages received at the NWSTG from the DAPS and Iridium are flagged with a special character if they are identified as being truncated or as having transmission parity errors. The data extraction routines will attempt to decode all the available data in the raw message, regardless if the message has been flagged as containing errors. Measurements which can't be decoded as a result of transmission errors are identified and flagged as missing. Wave and continuous wind measurements are hard flagged and not released if the message strings containing these data are found to have errors. If the need arises, a station may be

set to not release any data if the messages from the DAPS or Iridium are flagged as having transmission errors. This feature is rarely used since the data extraction routines are very robust and have been found to rarely decode and release erroneous data as a result of transmission errors. The feature is set using a parameter control in the NEMIS database interface, and subsequently at NWSTG.

V. OCEAN QUALITY CONTROL

In order to understand and predict the ocean, its properties must be monitored. NDBC helps to monitor the ocean by collecting surface currents, ocean current profiles, near surface temperature and water quality parameters. Included in the water quality parameters are turbidity, redox potential (Eh), pH, chlorophyll-a, and dissolved oxygen. These data are collected within the Weather Buoy and Tropical Atmosphere Ocean (TAO) programs. Weather buoy data are quality controlled in real-time and distributed over the Global Telecommunications System (GTS). TAO data are transmitted several times each day from the buoy using the Service Argos system. The TAO data are not quality controlled before being disseminated over the GTS. Daily quality control is applied in the Data Assembly Center and “bad” data may be prohibited from being disseminated the following day.

In this portion of the document, global quality control criteria will be assigned. As more ocean data are collected, regional and then buoy specific quality control criteria are possible.

The Quality Assurance of Real-Time Oceanographic Data (QARTOD) working group started with a small group of data managers and data providers located in the U.S., in the winter of 2003. QARTOD is a continuing multi-agency effort formed to address the quality assurance and quality control issues of the Integrated Ocean Observing System (IOOS) community. The first workshop was held at the NOAA NDBC office at Stennis Space Center, MS in the winter of 2003. Over 80 participants attended with the primary task of developing minimum standards for calibration, quality assurance (QA) and quality control (QC) methods, and metadata. The workshop resulted in a report that summarized the recommendations on these issues and on future workshops. QARTOD II (second workshop) was held February 28-March 2, 2005 in Norfolk, VA, and focused on QA/QC issues in HF radar measurements and wave and current measurements’ unique calibration and metadata requirements. QARTOD III was held on November 2-4, 2005 at the Scripps Institution of Oceanography, La Jolla, CA. It continued the work on waves and current measurements, as well as commencing work on CTD measurements and HF Radar. QARTOD IV was held at the Woods Hole Oceanographic Institution on June 21 - 23, 2006. Related materials are posted on the QARTOD website: <http://qartod.org>.

QARTOD addresses the challenges related to the collection, distribution and description of real-time oceanographic data. One of the primary challenges facing the oceanographic community will be the fast and accurate assessment of the quality of data streaming from the IOOS partner systems. Operational data aggregation and assembly from distributed data sources will be essential to the ability to adequately describe and predict the physical, chemical, and biological state of the coastal ocean. These activities demand a trustworthy and consistent quality description for every observation distributed as part of IOOS. Significant progress has been accomplished in previous workshops towards the definition of requirements both for data evaluation and relevant data flags for real-time QC.

A. Weather Buoy Currents

Surface currents are collected to support commerce, safety of operation, search and rescue, oil spill response, and currents near harbor entrances that impact ocean transportation. The surface data are also useful for comparison to High Frequency Radar-generated surface current data. NDBC acquires these measurements using buoy-mounted acoustic Doppler samplers. Surface currents are presently being collected using either the SonTek Argonaut MD or the Aanderaa Doppler Current Sensor.

Quality control of surface currents consists of monitoring measurements provided by the sensor and by analyzing the output currents. Two different current measuring systems are currently in use and the first quality control checks differ for each. Both include a measure of the transmitted beam strength, the received beam stream strength, number/percentage of good pings, and values of sensor movement (tilt/roll/pitch, etc).

B. Weather Buoy Current Profiles

Ocean current profiles provide the motion of the ocean in the water column. This information is essential for assessing oil response, search and rescue, stresses on offshore platforms, and input and validation for ocean models. At NDBC, these data are currently acquired from downward-looking, buoy- or cage-mounted systems. On offshore oil platforms, the current profiles may be downward looking from a number of levels in the water column, or upward-looking from a bottom-mounted system.

NDBC currently uses the Teledyne RDI Acoustic Doppler Current Profiler (ADCP) as the primary sensor for collection of ocean current profile data. ADCPs emit short-duration, high-frequency pulses of acoustic energy along narrow beams. Scatterers (assumed to be passive nekton and plankton) within the water column return the backscattered energy and the ADCPs resolve the along-beam Doppler frequency shifts into orthogonal earth coordinates to obtain ocean currents at various levels in the water column. The

Teledyne RDI ADCPs use four transducers, which allow redundancy and provides a better measure of the homogeneity of flow. TRDI has established a set of QA tests to insure that the data returned from the sensor is of good quality.

C. Weather Buoy Salinity

Salinity is required to measure the presence and movement of water masses in the ocean. Salinity is a derived product and some instruments provide the salinity directly (through internal calculations) and others provide the conductivity, temperature, and depth required to calculate the salinity. Salinity measurements have been made at a number of C-MAN stations and recently at a number of coastal buoys. Several different instruments have been used to measure the salinity. NDBC salinity measurements are based on the practical salinity scale using the empirical relationship between the salinity and conductivity of seawater. The salinity units are reported in practical salinity units (psu).

Salinity is calculated from the conductivity and temperature collected by the SeaBird 39-SM or the Falmouth Scientific Instruments (FSI) unit. Salinity is also provided by the Ocean Sensor Module (OSM), a derivative of the SeaKeepers 1000. Salinity is provided directly from the OSM unit.

VI. CONCLUSION

Today, NDBC provides IOOS[®] DAC services for 700 platforms – including 40 “partners” such as the 11 Regional Associations, universities, oil platforms and even a ferry service. The DAC provides 24/7 full-spectrum quality control of IOOS[®] real-time observations. DAC personnel reports station failures to data providers within three hours of determination, detects real-time data anomalies via manual and automated quality control methods and assigns WMO identifiers to enable the release of partner data in real-time to the GTS. Additionally, the DAC maintains platform metadata in a database for proper processing and archival at the NOAA data centers.

REFERENCES

- [1] WMO, 2006: Guide to Meteorological Instruments and Observations, WMO-No. 8, Seventh Edition, World Meteorological Organization, Geneva, Switzerland.

